Application of Nucleonica's Gamma Spectrum Generator and easyMonteCarlo Simulation Tools on Nuclear Security Issues

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Modeling of gamma spectra is required in various fields. The growth of usage of spectrometric border monitoring methods to combat illicit trafficking of nuclear and other radioactive materials enhances the need for such techniques. With the development of the Gamma Spectrum Generator within the Nucleonica web-portal (www.nucleonica.net) a new ansatz is made, which allows authorized experts to perform spectrum modeling on a PC, wherever web access is available. The spectrum modeling toolkit (Gamma Spectrum Generator and easyMonteCarlo) must address various aspects, such as different detectors and their direct environment, various radioactive sources, their geometries and materials, distances and absorbers. After showing the accuracy of the modeling tools, more sophisticated scenarios can be dealt with. As a first example the nuclear security relevant masking issue is investigated experimentally and in extensive simulations using the described modeling tools.

I. The Simulation Tools

The Gamma Spectrum Generator (GSG) [1] and the easyMonteCarlo (eMC) together form a powerful gamma simulation toolkit, developed at the Institute for Transuranium Elements in Karlsruhe. The modeling of realistic spectra uses a two step approach. First, offline particle tracking calculations are made, using an MCNP-based Monte Carlo engine, the easyMonteCarlo. The eMC uses a point detector tally and can take into account various extended source geometries as well as scattering objects in the experimental setup. Also the detector surroundings, as housing and electronics, can be introduced in the eMC. A physical spectrum is produced and translated into an equivalent point source, which is the starting point for the second step in the model, the Gamma Spectrum Generator (GSG). In the GSG, which can treat point sources only, the physical spectrum is folded with a precalculated realistic detector response from a database for various distances, detector types and sizes. The two step approach produces accurate gamma spectra in a minimum time.

II. Experimental Validation

Before the simulation toolkit can be applied to real-life issues relevant to nuclear security, their reliability has to be shown for clearly defined simple measurement setups. In a series of validation measurements, the simulations have been compared to spectra of spectrometric point sources and extended nuclear reference material, both shielded and unshielded, taken with a common handheld NaI scintillation detector, the ICX identiFINDER. Previous work included validation also for an HPGe detector, the Ortec detective, see [2] and [3]. In all cases, experiment and simulation agreed well. Fig. 1 shows the simulated and measured spectra for the NaI detector and a low enriched uranium standard shielded by 30mm of aluminum. The picture also includes a simulation using the GSG only, without Monte Carlo calculations. One can see that the attenuation and scattering effects in the extended source geometry strongly influence the spectrum shape.

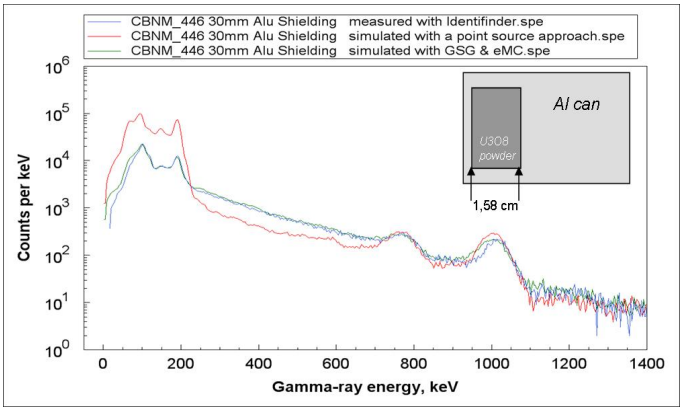

Fig. 1. Measured (blue), simulated (green) and simulated with the GSG only (red) NaI spectra of a 4.46 % enriched uranium standard shielded by 30mm of aluminum.

III. Practical Application

Having shown the accuracy of the tools they can now be applied to realistic problems with more sophisticated source and measurement geometries. In the present study, the nuclear security relevant 'masking', where one nuclide conceals another one in the spectrum, has been investigated. According to different properties of a real-life gamma spectrum, three different types of masking could be identified. Subsequently

Manuscript received October 29th, 2010.

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three scenarios using different source-combinations have been established. The chosen sources were paired following a categorization as innocent (natural, industrial or medical) or threat (nuclear) material.

The first type of masking is based on adjacent characteristic photopeaks in a spectrum, which need to be resolved and separated in order to identify the nuclides involved. This type is a priori resolution dependant, shown before by Keyser and Twomey [3]. An example are the close main lines of Ba-133 and Pu-239 in the region of 250 to 450 keV. In a HPGe spectrum the different lines are clearly visible, while in a NaI spectrum one can only see two indefinite bumps in the interesting energy region. Fig. 2 shows the simulated and measured NaI spectra for a plutonium standard containing 84 % of Pu-239 at certification date and a point-like Ba-133 calibration source.

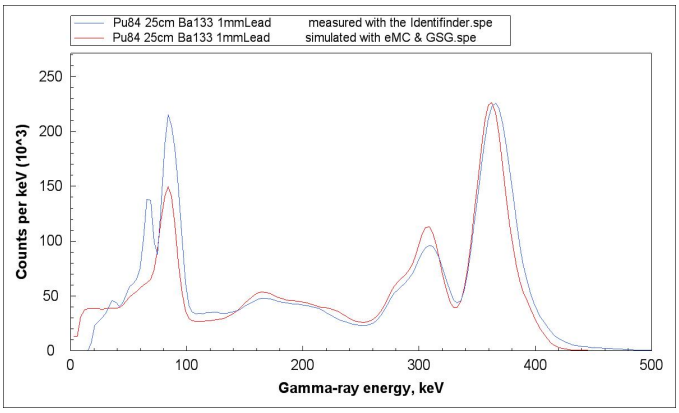

Fig. 2. Measured (blue) and simulated (red) NaI spectra of the CBNM Pu84 source shielded by 1mm of lead and the Ba-133 point source.

A second type of masking is the confusion of a photopeak of nuclear material with a so-called backscatter peak, which results from the scattering of photons in the detector surroundings (housing or electronics), introduced by Reinhard et al [4]. The new photon energy usually lies at around 200 keV and can be calculated for 180° scattering by simple conservation of energy and momentum. Unfortunately nuclear material also shows main energy lines in this region. An example is the combination of the industrial Cs-137, which shows a backscatter peak at 184 keV, and U-235 with its main line at 186 keV. Simulations show that the issue does not occur in HPGe spectra, as the scattering contribution is low compared to sharp photopeaks.

The third type of masking can occur by shielding an interested nuclide in a bulk volume of a gamma-emitter which shows a strong continuum. The chosen scenario for this yet undescribed but possible type of masking is a highly enriched uranium source (U-235) behind or in a bulk volume of naturally radioactive potash fertilizer, which contains K-40 (one gamma line at 1460 keV). The extended source produces a huge scattering contribution. Due to attenuation in the fertilizer volume, the uranium lines are shielded and also scattered and the remaining small peaks disappear in the strong K-40 continuum. Figure 3 shows the resulting spectra, both modeled and measured. To show the relevant change in shape, also the uranium spectrum alone is indicated. Also in this case, the better resolving HPGe detector could solve the issue, as the continuum is again small compared to sharp and prominent peaks.

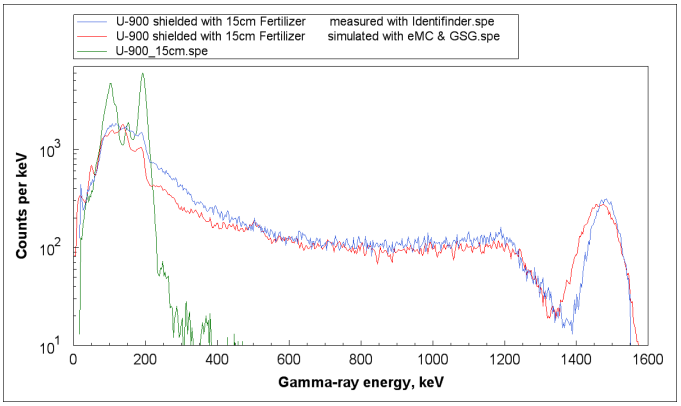

Fig. 3. Measured (blue) and simulated (red) NaI spectra for the NBS U900 high enriched uranium standard and the fertilizer volume. The uranium spectrum without fertilizer is indicated as well (green).

IV. Conclusions

For all three scenarios various simulations using different activity ratios of the masking and the masked nuclide have been performed in order to find the masking limit, the point where the nuclear material is fully concealed, for different detector types and identification algorithms. The spectra have been analyzed using a peak search based ID method. The NaI spectra could also be investigated using the identiFINDER built-in template matching, which compares spectra to a set of stored examples. This could be done by translating the simulated spectra into the identiFINDER file format and feeding them back into the device. The approach was shown to be a quick and reliable method for equipment testing. Using the described modeling tools, the masking issue could therefore be studied both qualitatively and quantitatively.

References

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